Recovery of 54 MA operation of Atlas using a crowbar in the vertical transmission line

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As currently envisioned, the Atlas pulse power system, with it's full complement of 38 Maintenance Units, will produce about 44 MA into a standard 68 g liner, while remaining within the reversal specification of the energy storage capacitors. Operation within the capacitor rating requires reduced charge voltage (53 kV absolute maximum) and a series resister of about 1mΩ, to produce a total 69 kV peak to valley (P-V) swing. While this operating point may be acceptable for many experiments, it is desirable to open the operating range up so operation at full charge voltage becomes possible. Under ordinary circumstances, operation at 60 kV would result in a 75 kV P-V swing using the present series resister and transmission line design, exceeding the rating of the capacitors.

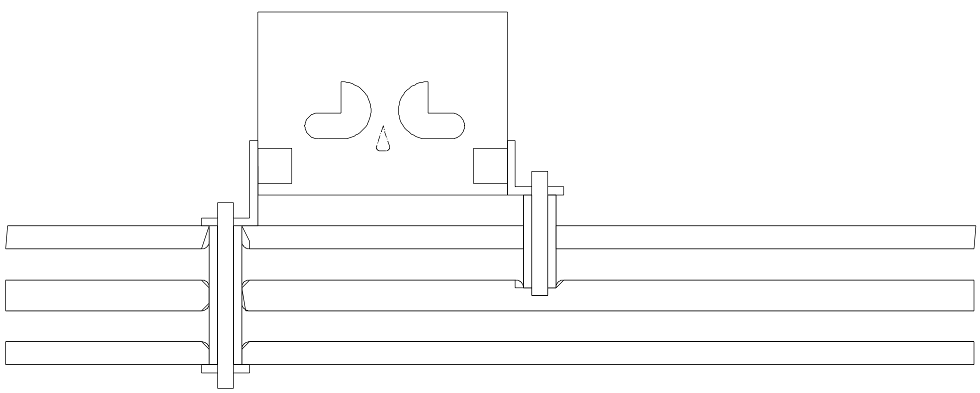

Figure 1. Layout drawing of a railgap assembly connected to a vertical transmission line. The drawing is to scale, with the gap itself having dimensions of 19.6" long x 5.9" tall x 7.73" wide, with a conducting length of 15.5".

One solution to this problem is a crowbar (CB) in the vertical transmission line, close to the storage system. Such a crowbar can be constructed of three railgaps (RG) on each vertical transmission line (VTL), in parallel, on the inside of each VTL between the two parallel lines in a trough. Such a layout is shown in Figure 1 above. The RG is held off the ground plate by a 1" oil gap, and connects both the ground plates together with a set of 5 posthole convolutes on the ground end of the gap. The center conductor is connected to the hot end of the gaps by another 5 postholes of half the length. The net inductance/RG of approximately 52 nH is composed of 25 nH from the RG + 16 nH from the additional volume under the gap + 11 nH from the 10 postholes used for each RG. This inductance is cut down by a factor of 3 in the configuration with three gaps in parallel. The total system is 60" in height if the gaps are aligned vertically, so it needs to be as close to the output switch, where the plates of the VTL are 64” tall, as possible. The total assembly is approximately 8” thick, so given the spacing between VTLs in the trough, the two switch assemblies may need to be staggered radially to fit in the available space.

The Atlas dynamic liner Spice model has been modified to include such a crowbar, and the operation of the pulsed power system into the standard liner with the 1mΩ series resister evaluated. The vertical transmission line circuits are shown in Figure 2. The crowbar is off the left side in each case, and shown for both a single VTL driven by 4 Marx modules in the upper circuit, and the 74 Marx equivalents in the two lower circuits. The liner is to the right side, and includes a power flow channel crowbar to ground. The two sets of CB switches (one real and one assuming the PFC breaks down) are both crowbarred at about 7.4 μs in normal operation with a 68 g standard liner, close to the time when the implosion hits the 5 mm ID point. The model liner inductance is clamped at the 5 mm diameter level after this. The details of this simple model are covered in an earlier report on the Spice model. For details see the

http://www-p24.lanl.gov/~watt/Atlas_dynamic_liner_spice_calcs971008.pdf

which describes the liner calculation and assumptions involved. A comparison between the liner currents achieved for 1 mΩ series resistance in the low voltage case without CB and the higher voltage case with CB is shown in Figure 3, along with the capacitor voltages in each case. The capacitor swing is kept at 66 kV in each case for caparison purposes. The result is that 60 kV operation becomes possible again with net liner current over 50 MA, compared to 44 MA operation at 50.5 kV charge and 66 kV swing without the crowbar. The implosion velocity increases by about 10% over the case without CB. As discussed in the earlier report, the liner velocities shown in Figure 4 are high estimates, as is the case of all single layer circuit models lacking a lot of the physics available in a code such as Crunch, but they do serve as an accurate predictor of the relative improvement in liner peak velocity that can be achieved by use of a crowbar. Peak crowbar current is 1.05 MA, well within the capability of the three parallel switches.

After the initial investigation of the efficacy of a crowbar in the VTL, which showed that an additional 6 MA could be pulled safely from the bank with the 1 mΩ series resister, a series of simulations was run in which the series resistance and time of the CB were also varied. The result of this run was the observation that the crowbar worked best when fired at approximately the same time as the PFC flashed over, i.e. at the 5 mm inner liner radius point in the model. If the CB fired more than a few hundred ns later than that, it had little effect on the reversal, which ultimately peaked at the non-crowbarred 75 kV value. If the VTL CB went earlier than the PFC flashover, the reversal eventually increased to levels exceeeding the 75 kV free running value because the bank saw a much lower net circuit impedance after peak current and rang more strongly. As the series resistance was lowered below about 0.6 $m\Omega$, the bank ringing increased to unacceptable levels regardless of the time delay between the crowbar and the flashover. The best operation within the reversal specification appears to come with around 0.55-0.6 $m\Omega$, at which point a maximum current of about 54 MA was achieved. This regains 10 MA beyond the 44 MA level currently envisioned for operation with a 1 $m\Omega$ series resister. Figure 5 shows the results of this study.

Nothing comes without caveats, of course, and this is no exception. The caveat here is the question of how well a railgap can be made to fire at a holdoff of only a few kV. The crowbar, to be effective, must actuate at near the zero crossing of the voltage waveform in the VTL, at least for the case with 1 $m\Omega$ series resistance. While people have successfully operated the Maxwell railgap at 10-20 kV, successful and reasonably low jitter operation at this low voltage, while still retaining the gap separation and gas pressure necessary to avoid self-break at the 200 kV transient level seen during the first half-cycle of the pulse, is not a given. Note that the operation with 0.6 $m\Omega$ series resistance has a collapse time much earlier than the 1 $m\Omega$ case, producing a voltage on the VTL CB at firing time that is still about 50 kV, so operation with this lower series resistance is probably more robust than with the higher value. Operation here would be less failsafe of course, due to the higher possible reversal if the crowbar failed to fire. The concept needs to be tested, but such a test is possible using the prototype Marx or the trigger system test Marx. Such a test must be done if this concept is to be pursued as a way to allow full voltage operation of Atlas.

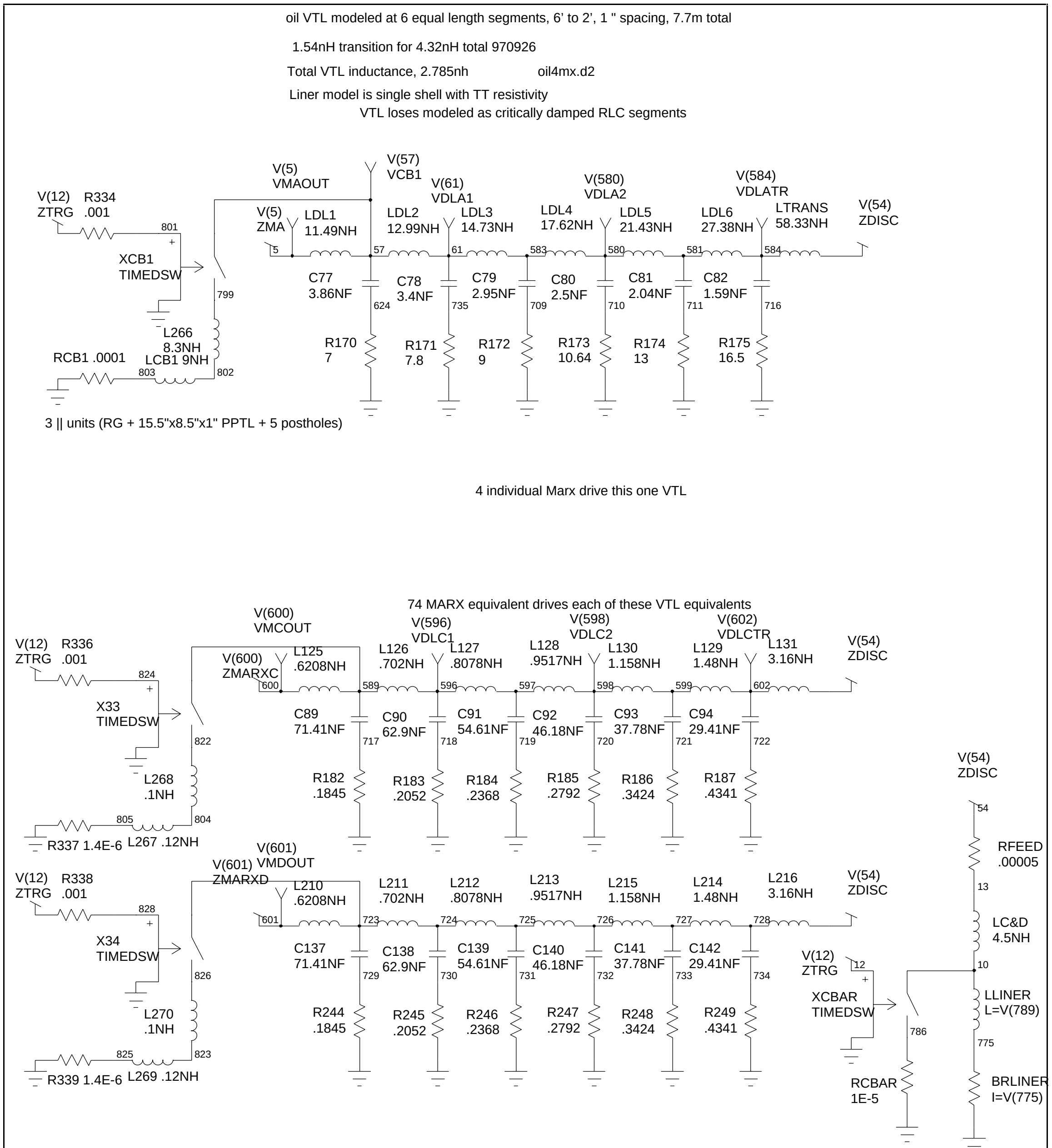

Figure 2. Vertical transmission line section of the dynamic liner Spice model, showing a crowbar in the early section of each VTL.

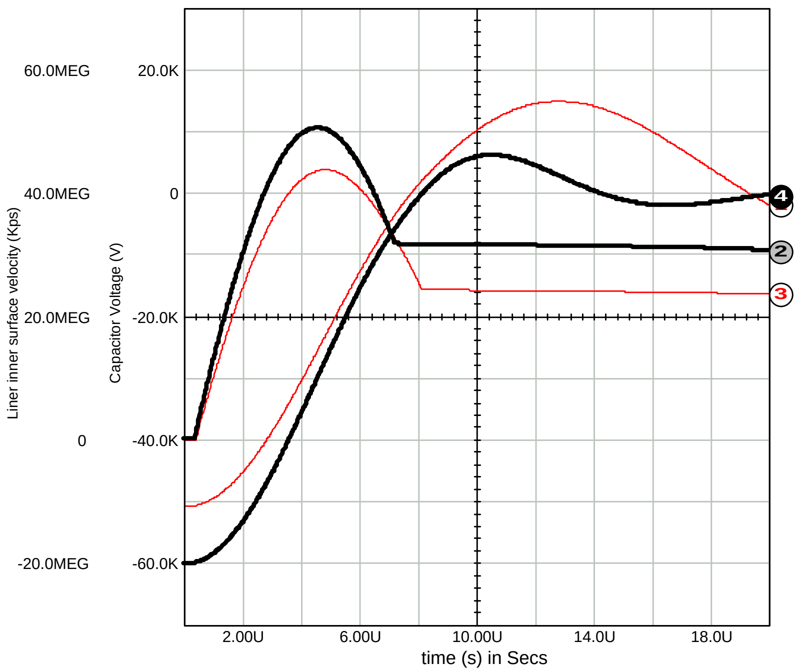

Figure 3. Comparison of liner current and capacitor voltage for a circuit without crowbar (thin curves) and a circuit with a crowbar in the VTL section (thick lines). The circuit without CB was run at 50.5 kV with 66 kV P-V swing, while the circuit with CB ran at the full 60 kV charge, and also swung 66 kV P-V. Both simulations assumed the normal 1 mΩ series resistance and a standard 68 g liner.

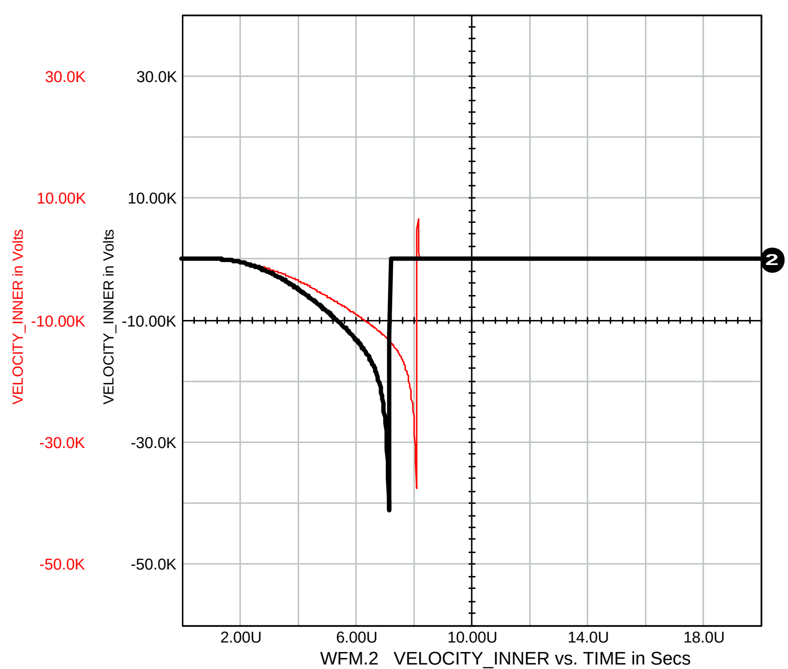

Figure 4. Comparison of final liner inner surface velocities with CB at full voltage and without CB at 50.5 kV. Again the thin line is the reduced voltage standard case without CB.

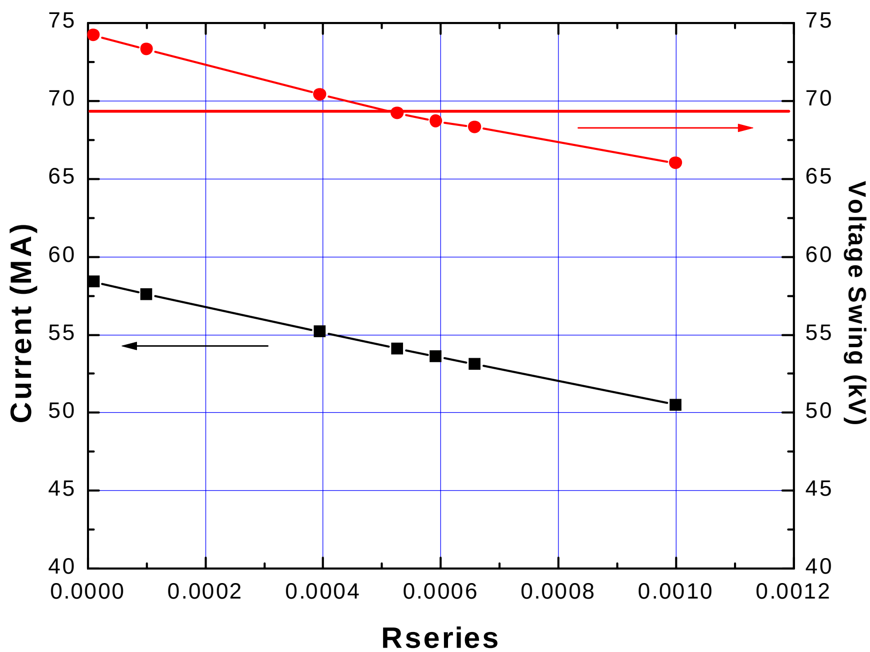

Figure 5. Attainable current vs. Rseries and Voltage swing vs. Rseries, for operation with a VTL crowbar fired with optimum timing. The horizontal bar at 69 kV is the allowable swing. For a swing of 69 kV, which occurs at approximately 0.55-0.6 mΩ, the current that can be attained is 54 MA, an increase of 10 MA over the normal reduced voltage, 1 mΩ figure of 44 MA with the assumed standard operation.